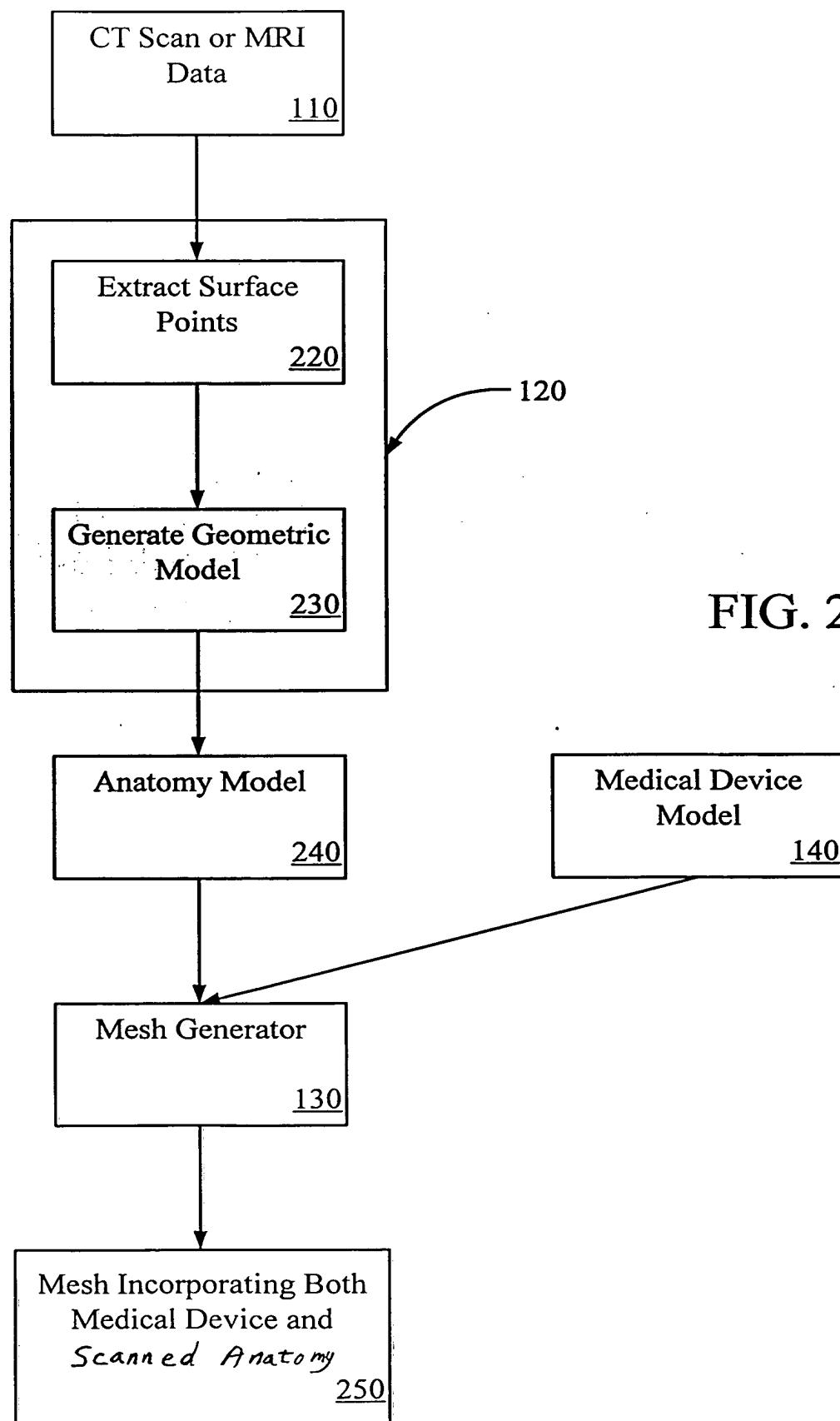


FIG. 1



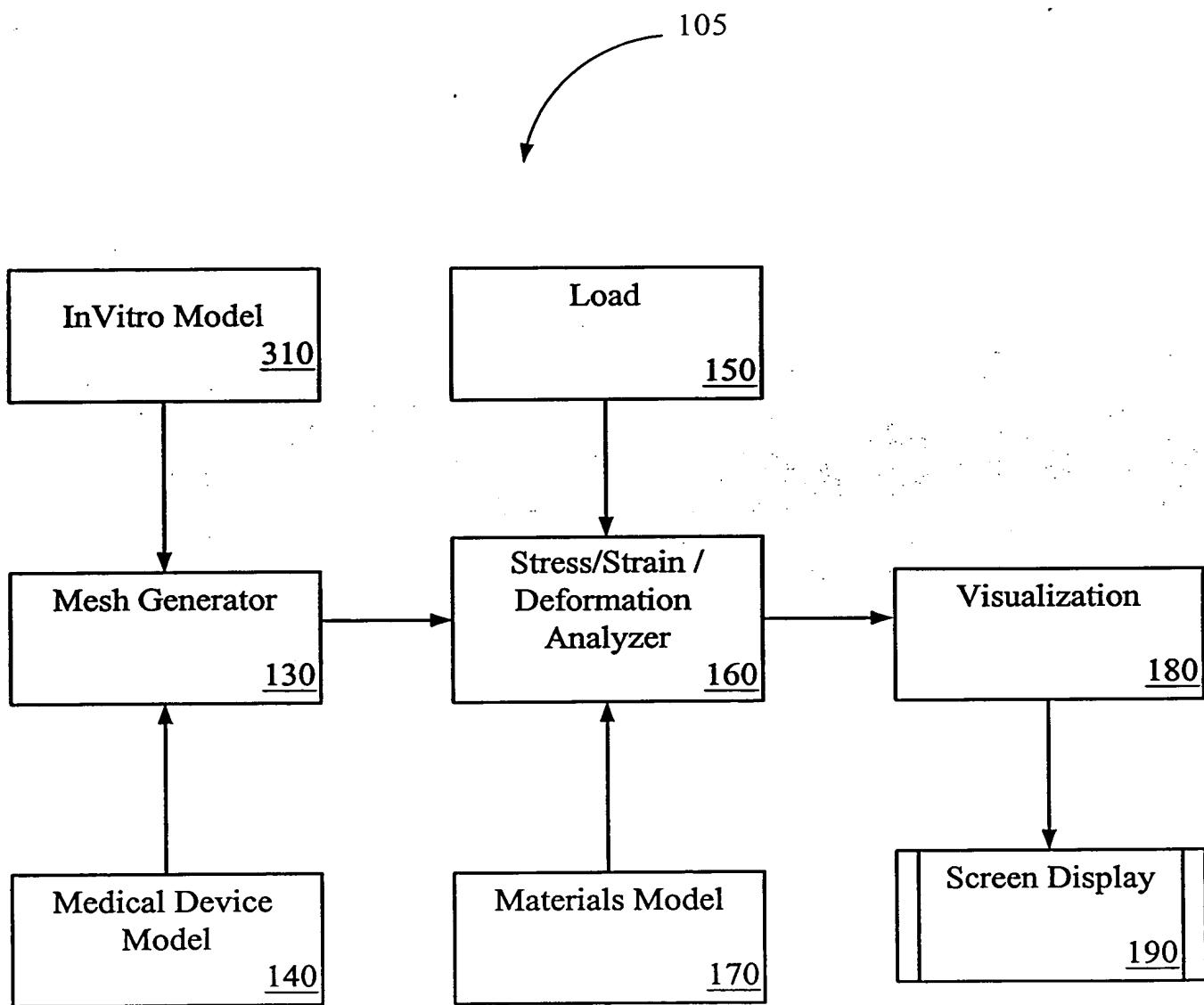


FIG. 3

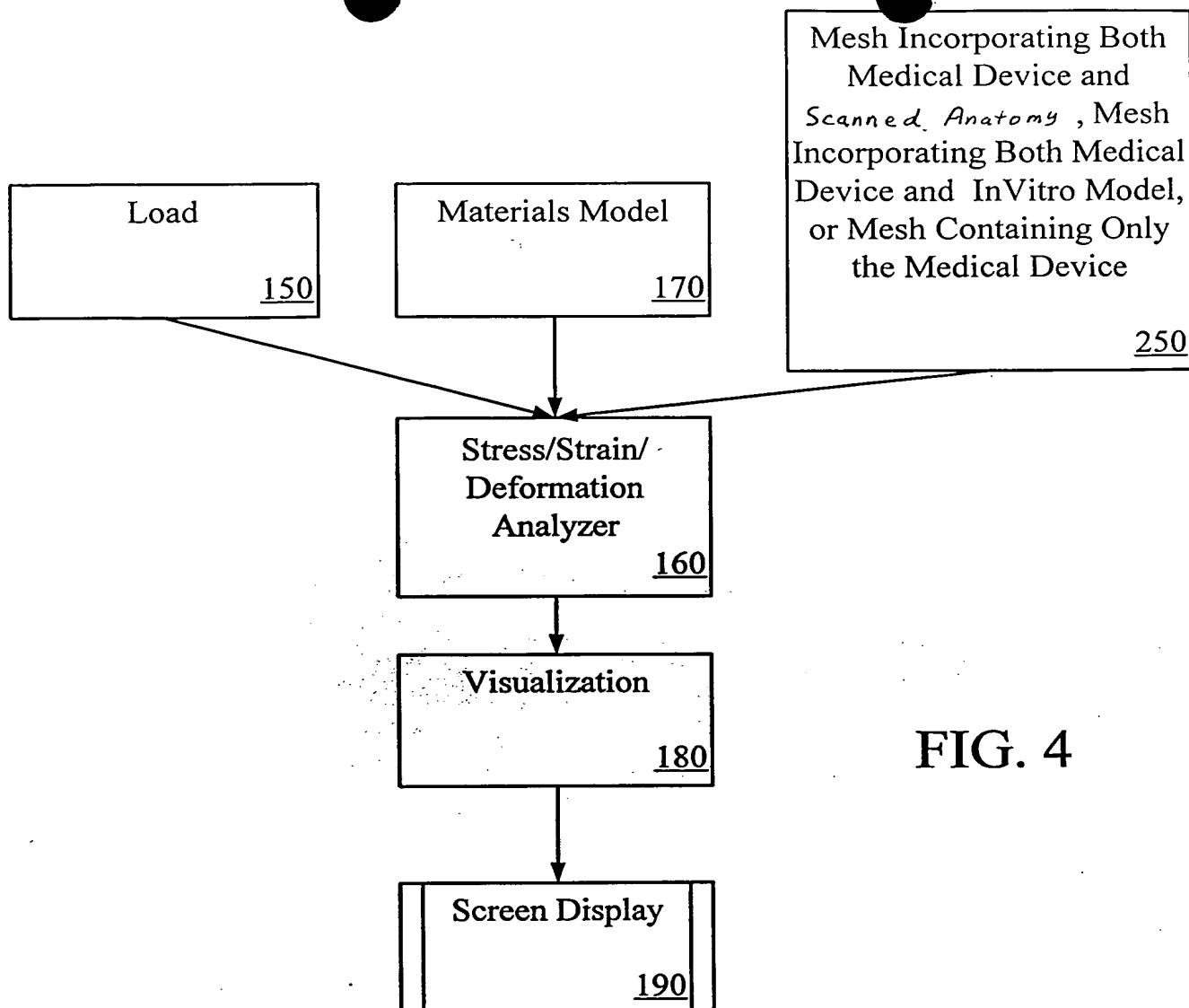


FIG. 4

FIG. 5A

Line Command

```

1  c *** Slotted Tube Integrated Stent Design Simulation: istent.run ****
2  c
3  c ----- parameter settings -----
4  c
5  c .... inike=1 => make nike file; inike=0 => make dyna file
6  c .... imodel = 0 => full 3 segment model with interconnects
7  c      = 1 => 3-crown segment only
8  c      = 2 => 6-crown segment only
9  c      = 3 => 12-crown segment only
10 c .... isym = 0 => full 360 deg model
11 c      = 1 => symmetric model
12 c .... isim_mode: type of simulation
13 c      = 1: => radial force to R_f = X% R_0, restoring stress mat'l
14 c      = 2: => flat plate force, restoring stress mat'l
15 c      = 3: => predelivery compression, loading stress mat'l
16 c      = 4: => initial expansion
17 c      = 5: => frequency analysis
18 c .... refine = X => add X elements via mseq in each direction
19 c          of the cross section
20 c
21 parameter inike 1 ;
22 parameter imodel 0 ;
23 parameter isym 0 ;
24 parameter isim_mode 4 ;
25 parameter refine 2 ;
26 c
27 para Tighten [0.9];   c helps 'tighten' or stiffen spline
28           c range (0.5,1) (probably should not change)
29 c
30 c ----- parameter settings -----
31 c
32 c .... ===== design parameters =====
33 c
34 c Note: Adjust specified OD for each segment considering the wall
35 c      thickness for that segment so that ID's match in a consistent
36 c      way for the tube blank from which they were cut.
37 c
38 c Upper segment --- 3 crowns
39 c Middle segment -- 6 crowns

```

FIG. 5B

Line Command

40 c Lower segment --- 12 crowns (conical)

41 c

42 c Parameters for 3-crown segment

43 c

44 para

45 RCyl3 [.5*2/25.4]

46 dCIA3 [-.00] c delta of center of inner arc for 3 crown segment (-:0)

47 dCOA3 [0] c delta of center of outer arc for 3 crown segment (0:+)

48 CW3 [.007] c Circumferential width of segments for 3 crowns

49 RW3 [.005] c Radial width for 3 crowns

50 NRA3 [.0095] c normal radius of smaller cylinders (arcs)

51 c for 3 crowns

52 Ht3 [0.224] c distance from center of upper arcs

53 c to center of lower arcs for 3 crowns

54 NLegEl3 [12]; c number of elements along the leg

55

56 c

57 c Parameters for 6-crown segment

58 c

59 para

60 RCyl6 [.5*2/25.4] c outside radius for 6 crown segment

61 dCIA6 [0] c delta of center of inner (smaller) arc for 6 crown segment(-:0)

62 dCOA6 [0.002] c delta of center of outer (larger) arc for 6 crown segment (0:+)

63 CW6 [.009] c Circumferential width of segments for 6 crowns

64 RW6 [.009] c Radial width for 6 crowns

65 NRA6 [.0105] c normal radius of smaller cylinders (arcs)

66 c for 6 crowns

67 Ht6 [.115] c distance from center of upper arcs

68 c to center of lower arcs for 6 crowns

69 NLegEl6 [12]; c number of elements along the leg

70

71 c

72 c Parameters for 12-crown segment

73 c

74 para

75 dCIA12 [0] c delta of center of inner arc for 12 crown segment (-:0)

FIG. 5C

Line Command

76 dCOA12 [0] c delta of center of outer arc for 12 crown segment
(0:+)

77 CW12 [.005] c Circumferential width of segments for 12 crowns

78 RW12 [.008] c Radial width for 12 crowns

79 NRA12 [.006] c normal radius of smaller cylinders (arcs)
c for 12 crowns

80 Ht12 [.050] c distance from center of upper arcs
c to center of lower arcs for 12 crowns
c (measured along the leg, not necessarily in
c the z direction)

85 c first outside radius for 12 crown segment (near other segments)

86 RCyl12_1 [.5*2/25.4 - (.016-%RW12)]

87 c second outside radius for 12 crown segment (bottom)

88 RCY12_2 [.5*1.4/25.4 - (.016-%RW12)]

89 c

90 NLegEl12 [10]; c number of elements along the leg

91 c

92 c

93 c Interconnects

94 c

95

96 c

97 c Upper interconnects

98 c

99 para HIUp [.02] c height of interconnect

100 FRUp [.005] c fillet radius for blend

101 ICWUp [.006] c circumferential width

102 IRWUp3 [.005] c radial width at 3-crown end

103 IRWUp6 [.006]; c radial width at 6-crown end

104

105 c

106 c S-interconnects

107 c

108 para SIVer [.01] c vertical distance between upper or lower arc centers
c also the distance from the vertical mid-line to
c the first arc center

111 SIHor [.010] c horizontal distance between upper two or
c lower two arc centers

112 SIr [.004] c arc radius

FIG. 5D

Line Command

```

114      SIR0 [%SIR+%ICWUp/2] c outer radius
115      SIRI [%SIR-%ICWUp/2]; c inner radius
116
117      c
118      c Lower interconnects
119      c
120      para HILr [.031] c height of interconnect
121          FRLr [.010] c fillet radius for blend
122          ICWLr [.007] c circumferential width
123          IRWLr6 [.005] c radial width at 6-crown end
124          IRWLr12 [.005]; c radial width at 12-crown end
125
126      c
127      c .... ===== design parameters =====
128      c
129      c .... set cylinder ID & OD for compression
130      c
131      if (%isim_mode.le.3) then
132          parameter ricompcyl
133              [1.1*max(%RCyl3,%RCyl6,%RCyl12_1,%RCyl12_2)];
134          parameter rocompcyl
135              [1.4*max(%RCyl3,%RCyl6,%RCyl12_1,%RCyl12_2)];
136          c
137          c .... set cylinder ID & OD for expansion
138          c
139          elseif (%isim_mode.eq.4) then
140              parameter rocompcyl
141                  [0.95*(min(%RCyl3,%RCyl6,%RCyl12_1,%RCyl12_2)-%RW6)];
142          parameter ricompcyl
143              [0.7*(min(%RCyl3,%RCyl6,%RCyl12_1,%RCyl12_2)-%RW6)];
144          endif
145          c
146          c Materials assignments
147          c
148          parameter matst12 3 ;
149          parameter matst6 4 ;
150          parameter matst3 5 ;

```

FIG. 5E

Line Command
148 parameter mati126 6 ;
149 parameter mati63 7 ;
150 c
151 c
152 if (%isim_mode.eq.1) then
153 echo *** Radial Force Simulation ***
154 elseif (%isim_mode.eq.2) then
155 echo *** Flat Plate Force Simulation ***
156 elseif (%isim_mode.eq.3) then
157 echo *** Predelivery Compression Simulation ***
158 elseif (%isim_mode.eq.4) then
159 echo *** Initial Expansion Simulation ***
160 elseif (%isim_mode.eq.5) then
161 echo *** Natural Frequency Analysis ***
162 else
163 echo !!! ERROR: illegal isim_mode !!!
164 interrupt
165 endif
166 c
167 c ----- analysis options -----
168 title stent initial expansion simulation
169 c
170 c *** DYNA3D Analysis Options ***
171 c
172 if (%inike.eq.0) then
173 echo Making DYNA3D input file
174 dyna3d
175 dynaopts
176 term 5.0e-5
177 plti 1.e-6
178 prti 5.0e-6
179 c
180 c DR options
181 c
182 itr 500
183 tolrx 1.0e-2
184 drdb
185 c
186 c thermal effects option - temp from load curve 1

FIG. 5F

Line Command
187 c
188 teo 1
189 c
190 tssf 0.0
191 c
192 c print initial time step size
193 c
194 c prtflg 1
195 c
196 c turn off (0) or on (1) SAND database flag
197 c
198 edsdf 0
199 c
200 nrest 90000
201 nrunr 95000 ;
202 c
203 c DYNA3D discrete nodes impacting surface - stent to cyl
204 c * one side (180 deg) *
205 c
206 sid 1 dni
207 c sfif
208 c mfif
209 pnlt 1.0e-0
210 pnltm 1.0e-0
211 ;
212 c
213 c DYNA3D discrete nodes impacting surface - stent to cyl
214 c * opposite side *
215 c
216 c sid 2 dni
217 c sfif
218 c mfif
219 c pnlt 1.0e-4
220 c pnltm 1.0e-4
221 c ;
222 c
223 c end DYNA3D commands
224 c
225 endif

Line Command
226 c
227 c
228 c *** NIKE3D Analysis Options ***
229 c
230 if (%inike.eq.1) then
231 echo Making NIKE3D input file . . .
232 nike3d
233 nikeopts
234 nstep 5
235 delt 0.2
236 anal stat
237 c
238 c step tol of 1e-8 seems OK for predel compression
239 c
240 if (%isim_mode.eq.1.or.%isim_mode.eq.2) then
241 dctl -1.0e-8
242 elseif (%isim_mode.eq.3) then
243 dctl -1.0e-6
244 endif
245 c
246 c max iterations per stiffness reform
247 c
248 nibsr 20
249 c
250 c max stiffness reforms per step
251 c
252 msrf 20 ;
253 c
254 c temperatures follow load curve 1
255 c ** manually add tref=1.0 on matl 2 control card cols 26-35 **
256 c
257 teo 1
258 if (%isim_mode.eq.1.or.%isim_mode.eq.2) then
259 iprt 1
260 elseif (%isim_mode.eq.3.or.%isim_mode.eq.4) then
261 iprt 25
262 endif
263 iplt 1
264 nsbrr 1

FIG. 5G

FIG. 5H

Line Command
265 stifcore 1
266 bfgscore
267 bwmo new
268 echo Bandwidth minimization ACTIVATED with "NEW" option
269 c
270 c element constitutive data incore
271 c
272 bfor 10
273 sfor 10
274 bef 11
275 c
276 c linear solver
277 c
278 lsolver fissle
279 c
280 c solid element stent contact surface
281 c
282 sid 1 sv
283 c
284 if (%isim_mode.eq.1) then
285 c
286 c
287 pnlt 1.0e-5
288 elseif (%isim_mode.eq.2) then
289 pnlt 0.00001
290 elseif (%isim_mode.eq.3) then
291 c
292 c essential to adjust penalty
293 c
294 pnlt 1.0e+4
295 elseif (%isim_mode.eq.4) then
296 pnlt 1.0e-5
297 c iaug 1 ;
298 endif
299 ;
300 c
301 c slidesurface between interconnects and segments
302 c
303 sid 2 tied

Line Command

304 ;

305 c

306 c NIKE3D shell geometric stiffness (HL only)

307 c

308 segs 1 ;

309 c

310 c end NIKE3D section

311 c

312 endif

313 c

314 c symmetry planes

315 c

316 if (%isym.eq.1) then

317 c

318 c Symmetric Model

319 c theta=-60 and +60 symmetry to remove rigid body modes

320 c

321 c plane 1

322 c 0.0 0.0 0.0

323 c [-sin(60)] [-cos(60)] 0.0

324 c 0.0005 symm ;

325 c plane 2

326 c 0.0 0.0 0.0

327 c [-sin(60)] [cos(60)] 0.0

328 c 0.0005 symm ;

329 c

330 else

331 c

332 c symmetry planes to remove rigid body modes for full model

333 c

334 plane 1

335 0.0 0.0 0.0

336 1.0 0.0 0.0

337 .0005 symm ;

338 plane 2

339 0.0 0.0 0.0

340 0.0 1.0 0.0

341 .0005 symm ;

342 c plane 3

FIG. 5I

Line Command
343 c 0.0 0.0 0.0
344 c 0.0 0.0 TBD
345 c .0005 symm ;
346 endif
347 c
348 c
349 if (%inike.eq.0) then
350 c
351 c Load Curves for DYNA3D **ADD DR FLAG TO INPUT FILE **
352 c
353 if (%isim_mode.eq.1) then
354 c
355 c radial force
356 c
357 lcd 1
358 0.000E+00 1.000E+00
359 7.500E-03 2.250E+04
360 1.000E-00 2.250E+04 ;
361 c 1.000E-02 3.000E+04
362 c 1.000E-00 3.000E+04 ;
363 elseif (%isim_mode.eq.2) then
364 c
365 c flat plate compression, lcd 1 not used (dummy definition)
366 c
367 quit
368 c
369 elseif (%isim_mode.eq.3) then
370 c
371 c predelivery compression strain
372 c
373 lcd 1
374 0.000E+00 1.000E+00
375 1.000E-02 2.008E+05
376 1.000E-00 2.008E+05 ;
377 endif
378 c
379 c load curve #2 only used for flat plate compression
380 c
381 lcd 2

FIG. 5J

Line Command
382 0.000E+00 0.000E+00
383 1.000E+00 0.000e-00 ;
384 endif
385 c
386 if (%inike.eq.1) then
387 c
388 c ***** Load Curves for NIKE3D *****
389 c
390 if (%isim_mode.eq.1) then
391 c
392 c radial force
393 c
394 lcd 1
395 0.000E+00 1.000E+00
396 1.000E+00 2.000E+03 ;
397 elseif (%isim_mode.eq.2) then
398 c
399 c flat plate compression
400 c
401 lcd 1
402 0.000E+00 1.000E+00
403 1.000E+00 0.000E+00 ;
404 elseif (%isim_mode.eq.3) then
405 c
406 c predelivery compression strain
407 c
408 lcd 1
409 0.000E+00 1.000E+00
410 1.000E+00 2.008E+03 ;
411 elseif (%isim_mode.eq.4) then
412 c
413 c initial expansion strain
414 c
415 lcd 1
416 c thermal load (activate TEO above)
417 c 0.000E+00 1.000E+00
418 c 1.000E+00 -2.008E+04 ;
419 c prescribed displacement
420 0.000E+00 0.000E+00

FIG. 5K

Line Command

```
421      1.000E+00 1.000E-02 ;
422  endif
423  c
424  c ----- stent parts -----
425  c
426  include irss.tg
427  c
428  c ----- stent materials -----
429  c
430  if (%inike.eq.1) then
431      if (%isim_mode.eq.1.or.%isim_mode.eq.2) then
432          include istent.mats_nike_solid
433          echo model for radial force/flat plate analysis
434      elseif (%isim_mode.eq.3) then
435          include istent.mats_compress_nike_solid
436          echo model for predelivery compression strain
437      elseif (%isim_mode.eq.4) then
438          include istent.mats_compress_nike_solid
439          echo model for initial expansion strain
440      endif
441  c
442  elseif (%inike.eq.0) then
443      if (%isim_mode.eq.1.or.%isim_mode.eq.2) then
444          include istent.mats_dyna_solid
445          echo model for radial force/flat plate analysis
446      elseif (%isim_mode.eq.3) then
447          include istent.mats_compress_dyna_solid
448          echo model for predelivery compression strain
449      elseif (%isim_mode.eq.4) then
450          include istent.mats_compress_dyna_solid
451          echo model for initial expansion strain
452      endif
453  endif
454  c
455  c .... cylindrical compression for radial force or predelivery compression
456  c
457  if (%isim_mode.eq.1.or.%isim_mode.eq.3.or.%isim_mode.eq.4) then
458  c
459      if (%isym.eq.1) then
```

FIG. 5L

Line Command

```
460      include cylinder.parts_sym
461      else
462      include cylinder.parts
463      endif
464      c
465      if (%inike.eq.1) then
466      include cylinder.materials_nike
467      elseif (%inike.eq.0) then
468      include cylinder.materials_dyna
469      endif
470      endif
471      c
472      stp .01
473      merge
474      c
```

FIG. 5M

```
1  c **** TPEG Inflatable Proximal Seal Simulation ****
2  c          (seal.run)
3  c          March, 1999
4  c
5  c ----- parameter settings -----
6  c
7  c .... analytical model aorta geometric parameters
8  c      (distortion is 4-lobe)
9  c
10 parameter r_aorta [10.0/25.4];
11 parameter thk_aorta [1.0/25.4];
12 parameter amp_plaque [0.0/25.4];
13 c
14 parameter ro_aorta [%r_aorta+%thk_aorta];
15 c
16 c .... -- TPEG Design Parameters --
17 c
18 parameter r_tpeg [10/25.4];
19 parameter r_ps [3/25.4];
20 parameter l_tpeg 2.0;
21 parameter l_flap 0.25;
22 c
23 parameter graft_wall_thick [6*0.0013];
24 parameter cuff_wall_thick [3*0.0013];
25 parameter flap_wall_thick [6*0.0013];
26 c
27 c
28 c .... Pressures and load curve assignments
29 c
30 parameter P_hemo 2.32;
31 parameter P_cuff 3.0;
32 c
33 parameter lc_hemo 1;
34 parameter lc_proxcuff 3;
35 c
36 c .... TPEG folding simulation parameters
37 c
38 parameter vel_fold 20.0;
39 parameter t_fold [0.25/%vel_fold];
40 parameter t_init 0.0e-3;
41 c
42 c
```

FIG. 6A

43 c ----- analysis options -----
44 title sc6.i Seal CT-Solid r_t=10mm r_ps=3mm P_cuff=3.0 990428
45 c
46 c *** DYNA3D Analysis Options ***
47 c
48 dyna3d
49 dynaopts
50 term 6.5e-2
51 plti 5.e-4
52 prti 2.5e-2
53 c
54 c DR options
55 c
56 itr 500
57 c
58 c increase DR tol to prevent convergence after compression before expansion
59 c
60 c tolrx 1.0e-6
61 tolrx 1.0e-12
62 drdb
63 c
64 tssf 0.9
65 c
66 c turn off (0) or on (1) SAND database flag
67 c
68 edsdf 0
69 c
70 nrest 90000
71 nrusr 5000 ;
72 c
73 c symmetry planes on xz and yz planes
74 c
75 plane 1
76 0.0 0.0 0.0
77 1.0 0.0 0.0 0.001 symm ;
78 plane 2
79 0.0 0.0 0.0
80 0.0 1.0 0.0 0.001 symm ;
81 c
82 c DYNA3D slidesurface: +x folder cylinder
83 c
84 sid 1 sv

FIG. 6B

000000T 52262960

```
85  pnlt 1.0
86  pnltm 1.0
87  pen
88  ;
89  c
90  c .... DYN3D slidesurface: -x folder cylinder
91  c
92  sid 2 sv
93  pnlt 1.0
94  pnltm 1.0
95  pen
96  ;
97  c
98  c
99  c .... DYN3D slidesurface: +y folder cylinder
100 c
101 sid 3 sv
102 pnlt 1.0
103 pnltm 1.0
104 pen
105 ;
106 c
107 c .... DYN3D slidesurface: -y folder cylinder
108 c
109 sid 4 sv
110 pnlt 1.0
111 pnltm 1.0
112 pen
113 ;
114 c
115 c .... DYN3D tpeg to aorta (aorta is master)
116 c
117 sid 5 sv
118 c
119 c .... solid element aorta
120 c
121 pnlt 0.1
122 pnltm 0.1
123 c
124 c .... shell element aorta
125 c
126 c pnlt 1.0
```

FIG. 6C

FIG. 6D

```

127  c pnltm 1.0
128  pen
129  ;
130  c
131  c .... load curve: hemodynamics **** ADD DR FLAG TO INPUT FILE ****
132  c
133  lcd 1
134  0.000E+00      0.000E+00
135  [%t_init+2*%t_fold+1.0e-3] 0.000e+00
136  [%t_init+2*%t_fold+2.0e-3] %P_hemo
137  1.000E+00      %P_hemo ;
138  c
139  c .... load curve: channel !! NOT USED !! **** ADD DR FLAG TO INPUT FILE ****
140  c
141  lcd 2
142  0.000E+00 0.000E+00
143  [%t_init+2*%t_fold+1.0e-3] 0.000e+00
144  [%t_init+2*%t_fold+2.0e-3] 0.000e-00
145  1.000E+00      0.000e-00 ;
146  c
147  c .... load curve: proximal cuff **** ADD DR FLAG TO INPUT FILE ****
148  c
149  lcd 3
150  0.000E+00 0.000E+00
151  [%t_init+2*%t_fold+1.0e-3] 0.000e+00
152  [%t_init+2*%t_fold+2.0e-3] %P_cuff
153  1.000E+00      %P_cuff ;
154  c
155  c .... load curve for +x folder cylinder motion/velocity
156  c
157  lcd 4
158  0.000E+00      0.000E+00
159  %t_init      0.000E+00
160  [%t_init+1.0E-04]      [-%vel_fold]
161  [%t_init+%t_fold]      [-%vel_fold]
162  [%t_init+%t_fold+1.0e-3] 0.000E+00
163  [%t_init+2*%t_fold+1.0e-3] 0.000e+00
164  [%t_init+2*%t_fold+2.0e-3] [2.0*%vel_fold]
165  [%t_init+3*%t_fold+2.0e-3] [2.0*%vel_fold]
166  [%t_init+3*%t_fold+3.0e-3] 0.000e+00
167  1.000E+00      0.000E+00 ;
168  c

```

FIG. 6E

```

169  c .... load curve for -x folder cylinder motion
170  c
171  lcd 5
172  0.000E+00      0.000E+00
173  %t_init      0.000E+00
174  [%t_init+1.000E-04]      [%vel_fold]
175  [%t_init+%t_fold]      [%vel_fold]
176  [%t_init+%t_fold+1.0e-3]  0.000E+00
177  [%t_init+2*%t_fold+1.0e-3] 0.000e+00
178  [%t_init+2*%t_fold+2.0e-3] [-2.0*%vel_fold]
179  [%t_init+3*%t_fold+2.0e-3] [-2.0*%vel_fold]
180  [%t_init+3*%t_fold+3.0e-3] 0.000e+00
181  1.000E+00      0.000E+00 ;
182  c
183  c .... load curve for +y folder cylinder motion
184  c
185  lcd 6
186  0.000E+00      0.000E+00
187  %t_init      0.000E+00
188  [%t_init+1.000E-04]      [-%vel_fold]
189  [%t_init+%t_fold]      [-%vel_fold]
190  [%t_init+%t_fold+1.0e-3]  0.000E+00
191  [%t_init+2*%t_fold+1.0e-3] 0.000e+00
192  [%t_init+2*%t_fold+2.0e-3] [2.0*%vel_fold]
193  [%t_init+3*%t_fold+2.0e-3] [2.0*%vel_fold]
194  [%t_init+3*%t_fold+3.0e-3] 0.000e+00
195  1.000E+00      0.000E+00 ;
196  c
197  c .... load curve for -y folder cylinder velocity
198  c
199  lcd 7
200  0.000E+00      0.000E+00
201  %t_init      0.000E+00
202  [%t_init+1.000E-04]      [%vel_fold]
203  [%t_init+%t_fold]      [%vel_fold]
204  [%t_init+%t_fold+1.0e-3]  0.000E+00
205  [%t_init+2*%t_fold+1.0e-3] 0.000e+00
206  [%t_init+2*%t_fold+2.0e-3] [-2.0*%vel_fold]
207  [%t_init+3*%t_fold+2.0e-3] [-2.0*%vel_fold]
208  [%t_init+3*%t_fold+3.0e-3] 0.000e+00
209  1.000E+00      0.000E+00 ;
210  c

```

211 c ----- parts and materials -----
212 c
213 c
214 c get CT-data meshed aorta; convert cm to inches
215 c
216 csc [1./2.54]
217 include tpeg.part_ct_aorta3
218 c
219 csc 1.0
220 c
221 c option for analytical aorta model
222 c
223 c include tpeg.part_eq_aorta
224 c
225 include tpeg.part_cuff1
226 include tpeg.part_folder2
227 c
228 include tpeg.materials_dyna
229 c
230 c use negative tols to prevent aorta nodes merging w/ folder cylinder
231 c nodes if they coincidentally become adjacent
232 c
233 c merge nodes within CT aorta part using rather loose tolerance
234 c
235 bptol 1 1 0.01
236 bptol 1 3 -1.0
237 bptol 1 4 -1.0
238 bptol 1 5 -1.0
239 bptol 1 6 -1.0
240 tp .001
241 c

FIG. 6F

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FIG. 7A

1 c
2 c tpeg.part_ct_aorta3
3 c April 15, 1999
4 c
5 c ----- Aortic Model for Inflatable TPEG Model -----
6 c Derived from Patient CT Data
7 c Outer surface constructed with 0.52 mm offset from inner
8 c
9 c this is an aortic mesh file which surrounds the neck of the
10 c 3-D AAA reconstruction with solid elements.
11 c
12 c This file uses TrueGrid planes, oriented by eye using trial
13 c and error graphically, to determine an orthonormal section.
14 c Trick there is to adjust surface until walls of proximal neck section
15 c are parallel to global z axis. Use rz to rotate screen to find values,
16 c then use in surface transformation to position CT data for meshing.
17 c
18 c import IGES file containing surface data from CT scan
19 c
20 iges solid1.igs 1 1 mx -18.54 my -16.8 ry 24 rx 22 mz 4.8;
21 c
22 c inner surface
23 c
24 sd 17 sds 9 12;
25 c
26 c outer surface
27 c
28 sd 18 sds 15 16 ;
29 c
30 sd 201 plan
31 0 0 1.5
32 0 0 1
33 sd 202 plan
34 0 0 2.5
35 0 0 1
36 sd 203 plan
37 0 0 -2.3
38 0 0 1
39 sd 204 plan
40 0 0 3.3
41 0 0 1
42 sd 301 cy 0 0 0 0 0 1 1.35

FIG. 7B

43 sd 401 plan
 44 0. 0. 0.
 45 0. 1. 0.
 46 c
 47 c adjust mz to position part at cuff on Z-axis;
 48 c cuff may be z=[2,2.15]
 49 cylinder
 50 1 2;
 51 1 2 3;
 52 1 2 3 4 ;
 53 c
 54 1.0 1.25
 55 0 180.0 360.0
 56 -2.3 1.5 2.5 3.3
 57 c
 58 mseq i 2
 59 mseq j 29 29
 60 mseq k 20 5 5
 61 c
 62 c project top and bottom ends of aorta segment onto orthonormal planes
 63 c
 64 sfi ; ; -2; sd 201
 65 sfi ; ; -3; sd 202
 66 c
 67 c project top of upper neck segment onto orthonormal plane
 68 c
 69 sfi ; ; -4; sd 204
 70 c
 71 c project bottom of lower neck segment onto orthonormal plane
 72 c after radially expanding bottom ring by delta-r=2.0
 73 mbi -1; ; -1; x 2.0
 74 mbi -2; ; -1; x 2.0
 75 sfi ; ; -1; sd 203
 76 c
 77 c project inner cylinder surface onto aorta luminal surface
 78 c
 79 sfi -1; 1 3; 2 3; sd 17
 80 sfi -1; 1 3; 3 4; sd 17
 81 sfi -1; 1 3; 1 2; sd 17
 82 c
 83 c project outer cylinder onto aorta outer wall surface
 84 c

FIG. 7C

85 sfi -2; 1 3; 2 3; sd 18
86 sfi -2; 1 3; 3 4; sd 18
87 sfi -2; 1 3; 1 2; sd 18
88 c
89 c project theta=0/360 seam onto a plane to facilitate merging
90 c
91 sfi 1 2; -1; ; sd 401
92 sfi 1 2; -3; ; sd 401
93 c
94 c
95 c ... --- slidesurface definition with TPEG body ---
96 c
97 orpt + 0. 0. 3.0
98 sii -1; 1 3; 3 4; 5 m
99 c
100 c +y hemicylinder is material 11; -y is mat 12
101 c
102 mti ; 1 2; 2 4 ; 11
103 mti ; 2 3; 2 4; 12
104 c
105 c rigid material for aneurysm sac
106 c
107 mti ; 1 3; 1 2; 13
108 c
109 c Boundary Conditions
110 c * fix proximal end only in z
111 c
112 bi ; ; -4; dz 1 ;
113 c
114 c adjust mz to position aorta at cuff on Z-axis;
115 c cuff may be z=[2,2.15]
116 lct 1
117 mz [1.01*2.54] mx 0.7; ;
118 lrep 1 ;
119 endpart
120 c

FIG. 8A

```

1  c ***** Slotted Tube Integrated Stent Design Simulation *****
2  c          (istent.run)
3  c      Stent design analysis & CT-Anatomy simulation
4  c
5  c ----- parameter settings -----
6  c
7  c .... inike=1 => make nike file; inike=0 => make dyna file
8  c .... imodel = 0 => full 3 segment model with interconnects
9  c          = 1 => 3-crown segment only
10 c          = 2 => 6-crown segment only
11 c          = 3 => 12-crown segment only
12 c .... isym = 0 => full 360 deg model
13 c          = 1 => symmetric model
14 c .... isim_mode: type of simulation
15 c          = 1: => radial force to R_f = 80% R_0, restoring stress mat'l
16 c          = 2: => flat plate force, restoring stress mat'l
17 c          = 3: => predelivery compression to 12 F, loading stress mat'l
18 c          = 4: => initial expansion
19 c          = 5: => frequency analysis
20 c          = 6: => anatomy deployment
21 c .... refine = X => add X elements via mseq in each direction
22 c          of the cross section
23 c
24 c !!! warning - only 1st 8 characters of variable unique !!!! 
25 c
26 parameter inike 1 ;
27 parameter imodel 2 ;
28 parameter isym 0 ;
29 parameter isim_mode 6 ;
30 parameter refine 1 ;
31 c
32 para Tighten [0.9];   c helps 'tighten' or stiffen spline
33 c range (0.5,1) (probably should not change)
34 c
35 c ----- parameter settings -----
36 c
37 c .... ===== design parameters =====
38 c
39 c Note: Adjust specified OD for each segment considering the wall thickness
40 c for that segment so that ID's match in a consistent way for the
41 c tube blank from which they were cut.
42 c
43 c Upper segment --- 3 crowns
44 c Middle segment -- 6 crowns
45 c Lower segment --- 12 crowns (could be conical)
46 c
47 c Parameters for 3-crown segment
48 c
49 para

```

FIG. 8B

50 RCyl3 [29*0.5/25.4]
 51 dCIA3 [-.00] c delta of center of inner arc for 3 crown segment (-:0)
 52 dCOA3 [0] c delta of center of outer arc for 3 crown segment (0:+)
 53 CW3 [.020] c Circumferential width of segments for 3 crowns
 54 RW3 [.018] c Radial width for 3 crowns
 55 NRA3 [.0195] c normal radius of smaller cylinders (arcs)
 56 c for 3 crowns
 57 Ht3 [1.048] c distance from center of upper arcs
 58 c to center of lower arcs for 3 crowns
 59 NLegEl3 [12]; c number of elements along the leg
 60 c
 61 c Parameters for 6-crown segment
 62 c
 63 para
 64 RCyl6 [29*0.5/25.4] c outside radius for 6 crown segment
 65 dCIA6 [0] c delta of center of inner (smaller) arc for 6 crown segment (-:0)
 66 dCOA6 [0.005] c delta of center of outer (larger) arc for 6 crown segment (0:+)
 67 CW6 [.020] c Circumferential width of segments for 6 crowns
 68 RW6 [.018] c Radial width for 6 crowns
 69 NRA6 [.0195] c normal radius of smaller cylinders (arcs)
 70 c for 6 crowns
 71 Ht6 [.310] c distance from center of upper arcs
 72 c to center of lower arcs for 6 crowns
 73 NLegEl6 [12]; c number of elements along the leg
 74 c
 75 c Parameters for 12-crown segment
 76 c
 77 para
 78 dCIA12 [0] c delta of center of inner arc for 12 crown segment (-:0)
 79 dCOA12 [0] c delta of center of outer arc for 12 crown segment (0:+)
 80 CW12 [.008] c Circumferential width of segments for 12 crowns
 81 RW12 [.008] c Radial width for 12 crowns
 82 NRA12 [.006] c normal radius of smaller cylinders (arcs)
 83 c for 12 crowns
 84 Ht12 [.164] c distance from center of upper arcs
 85 c to center of lower arcs for 12 crowns
 86 c (measured along the leg, not necessarily in
 87 c the z direction)
 88 c first outside radius for 12 crown segment (near other segments)
 89 RCyl12_1 [22*0.5/25.4]
 90 c second outside radius for 12 crown segment (bottom)
 91 RCYl12_2 [20*0.5/25.4]
 92 c
 93 NLegEl12 [10]; c number of elements along the leg
 94 c
 95 c Interconnects
 96 c
 97 c Upper interconnects
 98 c

FIG. 8C

```

99 para
100 c HIUp [.10] c height of interconnect
101 HIUp [.20] c height of interconnect
102 FRUp [.016] c fillet radius for blend
103 ICWUp [.010] c circumferential width
104 IRWUp3 [.016] c radial width at 3-crown end
105 IRWUp6 [.016]; c radial width at 6-crown end
106 c
107 c S-interconnects
108 c
109 para
110 c SIVer [.03] c vertical distance between upper or lower arc centers
111 SIVer [.06] c vertical distance between upper or lower arc centers
112 c also the distance from the vertical mid-line to
113 c the first arc center
114 SIIHor [.0125] c horizontal distance between upper two or
115 c lower two arc centers
116 SIr [.008] c arc radius
117 SIrO [%SIr+%ICWUp/2] c outer radius
118 SIrI [%SIr-%ICWUp/2]; c inner radius
119 c
120 c Lower interconnects
121 para
122 c HILr [.071] c height of interconnect
123 HILr [.142] c height of interconnect
124 FRLr [.016] c fillet radius for blend
125 ICWLr [.016] c circumferential width
126 IRWLr6 [.005] c radial width at 6-crown end
127 IRWLr12 [.005]; c radial width at 12-crown end
128 c
129 c .... ===== design parameters =====
130 c
131 c .... set cylinder ID & OD for compression
132 c
133 if (%isim_mode.le.3.or.%isim_mode.eq.6) then
134 parameter ricompcyl [1.1*max(%RCyl3,%RCyl6,%RCyl12_1,%RCyl12_2)] ;
135 parameter rocompcyl [1.4*max(%RCyl3,%RCyl6,%RCyl12_1,%RCyl12_2)] ;
136 c
137 c .... set cylinder ID & OD for expansion
138 c
139 elseif (%isim_mode.eq.4) then
140 parameter rocompcyl [0.95*(min(%RCyl3,%RCyl6,%RCyl12_1,%RCyl12_2)-%RW6)] ;
141 parameter ricompcyl [0.7* (min(%RCyl3,%RCyl6,%RCyl12_1,%RCyl12_2)-%RW6)] ;
142 endif
143 c
144 c Materials assignments
145 c
146 parameter matst12 3 ;
147 parameter matst6 4 ;

```

FIG. 8D

```

148 parameter matst3 5 ;
149 parameter mati126 6 ;
150 parameter mati63 7 ;
151 c
152 if (%isim_mode.eq.1) then
153   echo *** Radial Force Simulation ***
154 elseif (%isim_mode.eq.2) then
155   echo *** Flat Plate Force Simulation ***
156 elseif (%isim_mode.eq.3) then
157   echo *** Predelivery Compression Simulation ***
158 elseif (%isim_mode.eq.4) then
159   echo *** Initial Expansion Simulation ***
160 elseif (%isim_mode.eq.5) then
161   echo *** Natural Frequency Analysis ***
162 elseif (%isim_mode.eq.6) then
163   echo *** Anatomy Deployment Simulation ***
164 else
165   echo !!! ERROR: illegal isim_mode !!!
166   interrupt
167 endif
168 c
169 c ----- analysis options -----
170 title human-size stent anatomy deployment
171 c
172 c *** DYNA3D Analysis Options ***
173 c
174 if (%inike.eq.0) then
175   echo Making DYNA3D input file
176 dyna3d
177   dynaopts
178   term 2.0e-4
179   plti 1.e-4
180   prti 5.0e-6
181 c
182 c .... DR options
183 c
184 c itr 500
185 c tolrx 1.0e-6
186 c drdb
187 c
188 c .... thermal effects option - temp from load curve 1
189 c
190 if (%isim_mode.ne.5) then
191   teo 1
192 endif
193 c
194 tssf 0.0
195 c
196 c print initial time step size

```

FIG. 8E

```

197  c
198  c prtflg 1
199  c
200  c .... turn off (0) or on (1) SAND database flag
201  c
202  edsdf 0
203  c
204  nrest 90000
205  nrunr 95000 ;
206  c
207  c .... DYNA3D stent to compression cyl
208  c
209  sid 1 dni
210  c sfif
211  c mfif
212  pnlt 1.0e-0
213  pnltm 1.0e-0
214  ;
215  c
216  c .... DYNA3D tied interface to interconnects if multisegment
217  c
218  if (%imodel.eq.0) then
219  sid 2 tied
220  ;
221  endif
222  c
223  c .... end DYNA3D commands
224  c
225  endif
226  c
227  c *** NIKE3D Analysis Options ***
228  c
229  if (%inike.eq.1) then
230  echo Making NIKE3D input file ...
231  nike3d
232  nikeopts
233  c
234  c .... temperatures follow load curve 1
235  c ** manually add tref=1.0 on matl 2 control card cols 26-35 **
236  c
237  teo 1
238  c
239  if (%isim_mode.eq.5) then
240  anal dyn
241  neig 20
242  shift 69
243  iplt 1
244  nsbrr 1
245  stifcore 1

```

FIG. 8F

```

246 bfgscore
247 bwm0 new
248 c
249 c element constitutive data incore
250 c
251 bfor 10
252 sfor 10
253 bef 11
254 c
255 c .... linear solver
256 c
257 lsolver fissle
258 c
259 elseif (%isim_mode.ne.5) then
260 c
261 c .... time step analysis
262 c
263 nstep 100
264 delt 0.0100
265 anal stat
266 c
267 c .... step tol of 1e-2 is OK for predel compression
268 c
269 if (%isim_mode.eq.1.or.%isim_mode.eq.2) then
270   dctl -1.0e-3
271 elseif (%isim_mode.eq.3) then
272   dctl -1.0e-2
273 endif
274 c
275 c .... max iterations per stiffness reform
276 c
277 nibsr 20
278 c
279 c .... max stiffness reforms per step
280 c
281 msrf 20 ;
282 if (%isim_mode.eq.1.or.%isim_mode.eq.2) then
283   iprt 1
284 elseif (%isim_mode.eq.3.or.%isim_mode.eq.4) then
285   iprt 25
286 endif
287 iplt 1
288 nsbrr 1
289 stifcore 1
290 bfgscore
291 bwm0 new
292 echo Bandwidth minimization ACTIVATED with "NEW" option
293 c
294 c element constitutive data incore

```

FIG. 8G

```
295 c
296 bfor 10
297 sfor 10
298 bef 11
299 c
300 c .... linear solver
301 c
302 lsolver fissle
303 c
304 c .... solid element stent contact surface
305 c
306 sid 1 sv
307 c
308 if (%isim_mode.eq.1) then
309 c
310 c .... below changed for sharp-edge laser-cut stent
311 c
312 pnlt 1.0e-3
313 elseif (%isim_mode.eq.2) then
314 pnlt 0.01
315 elseif (%isim_mode.eq.3) then
316 c
317 c .... essential to cut penalty for laser-cut stent predel compression
318 c
319 pnlt 0.001
320 elseif (%isim_mode.eq.4) then
321 pnlt 1.0e-3
322 c iaug 1 ;
323 endif
324 ;
325 c
326 c .... end block for time step only analysis
327 c
328 endif
329 c
330 c .... slidesurface between interconnects and segments
331 c
332 sid 2 tied
333 ;
334 c
335 c .... slidesurface between stent and aortic wall
336 c
337 if (%isim_mode.eq.6) then
338 echo *** Add activation time of 0.5 to slidesurface 2 ***
339 sid 3 sv
340 ;
341 endif
342 c
343 c .... NIKE3D shell geometric stiffness (HL only)
```

FIG. 8H

```

344 c
345   segs 1 ;
346 c
347 c .... end NIKE3D section
348 c
349 endif
350 c
351 c .... symmetry planes (omit for freq analysis)
352 c
353 if (%isim_mode.ne.5) then
354 if (%isym.eq.1) then
355 c
356 c .... Symmetric Model
357 c
358 c plane 1
359 c  0.0 0.0 0.0
360 c  [-sin(60)] [-cos(60)] 0.0
361 c  0.0005 symm ;
362 c plane 2
363 c  0.0 0.0 0.0
364 c  [-sin(60)] [cos(60)] 0.0
365 c  0.0005 symm ;
366 c
367 else
368 c
369 c .... symmetry planes to remove rigid body modes for full model
370 c
371 plane 1
372   0.0 0.0 0.0
373   1.0 0.0 0.0
374   .0005 symm ;
375 plane 2
376   0.0 0.0 0.0
377   0.0 1.0 0.0
378   .0005 symm ;
379 endif
380 endif
381 c
382 c
383 if (%inike.eq.0) then
384 c
385 c .... Load Curves for DYNA3D **** ADD DR FLAG TO INPUT FILE ****
386 c
387 if (%isim_mode.eq.1) then
388 c
389 c .... radial force
390 c
391 lcd 1
392   0.000E+00 1.000E+00

```

FIG. 8I

```

393      7.500E-03 2.250E+02
394      1.000E-00 2.250E+02 ;
395 elseif (%isim_mode.eq.2) then
396 c
397 c .... flat plate compression, lcd 1 not used (dummy definition)
398 c
399 echo !!! Flat plate not implemented for DYNA3D !!!
400 quit
401 c
402 elseif (%isim_mode.eq.3) then
403 c
404 c .... predelivery compression strain - 0.87 in. dia compressed to 12F
405 c      [check x-displ of stent center node to verify]
406 c
407 lcd 1
408      0.000E+00 1.000E+00
409      1.000E-02 1.008E+03
410      1.000E-00 1.008E+03 ;
411 elseif (%isim_mode.eq.6) then
412 c
413 c .... anatomy deployment
414 c      (LC from radial comp)
415 c
416 lcd 1
417      0.000E+00 1.000E+00
418      7.500E-04 1.000E+03
419      9.000E-04 1.000E+03
420      1.500E-03 1.000E+00
421      1.000E-00 1.000E+00 ;
422 endif
423 c
424 c .... load curve #2 only used for flat plate compression
425 c
426 lcd 2
427      0.000E+00 0.000E+00
428      1.000E+00 0.000e-00 ;
429 endif
430 c
431 if (%inike.eq.1) then
432 c
433 c .... ***** Load Curves for NIKE3D *****
434 c
435 if (%isim_mode.eq.1) then
436 c
437 c .... radial force
438 c
439 lcd 1
440      0.000E+00 1.000E+00
441      1.000E+00 3.000E+02 ;

```

FIG. 8J

```

442 elseif (%isim_mode.eq.2) then
443 c
444 c .... flat plate compression, lcd 1 not used (dummy definition)
445 c
446 lcd 1
447   0.000E+00 1.000E+00
448   1.000E+00 0.000E+00 ;
449 elseif (%isim_mode.eq.3) then
450 c
451 c .... predelivery compression strain - 0.87 in. dia compressed to 12F
452 c      [check x-displ of stent center node to verify]
453 c
454 lcd 1
455   0.000E+00 1.000E+00
456   1.000E+00 1.008E+03 ;
457 elseif (%isim_mode.eq.4) then
458 c
459 c .... initial expansion strain - 4/5 mm OD to 15/27 mm OD
460 c      [check x-displ of stent center node to verify]
461 c
462 lcd 1
463 c .... thermal load (activate TEO above)
464   0.000E+00 1.000E+00
465   1.000E+00 -1.008E+03 ;
466 c .... prescribed displacement
467 c   0.000E+00 0.000E+00
468 c   1.000E+00 1.000E-01 ;
469 c
470 elseif (%isim_mode.eq.5) then
471 c
472 c .... must define load curve since TEO active even if unused for freq
473 c
474 c .... initial expansion strain - 4/5 mm OD to 15/27 mm OD
475 c      [check x-displ of stent center node to verify]
476 c
477 lcd 1
478 c .... thermal load (activate TEO above)
479   0.000E+00 1.000E+00
480   1.000E+00 -1.008E+03 ;
481 elseif (%isim_mode.eq.6) then
482 c
483 c .... anatomy deployment - 0.87 in. dia compressed to 12F
484 c
485 lcd 1
486   0.000E+00 1.000E+00
487   0.500E+00 5.000E+02
488   1.000E+00 1.000E+00 ;
489 endif
490 endif

```

FIG. 8K

```

491 c
492 c ----- stent parts -----
493 c
494 include irss.tg
495 c
496 c ----- anatomy parts -----
497 c
498 if (%isim_mode.eq.6) then
499 c
500 c .... convert anatomy data from cm to inch units
501 c
502 control
503 csca [1./2.54]
504 c
505 c .... import meshed anatomy data for stent deployment
506 c (this is an aortic stent)
507 c
508 include tpeg.part_ct_aorta3
509 csca 1.0
510 merge
511 if (%inike.eq.1) then
512 c
513 c .... set material properties for aortic wall
514 c
515 include aorta.materials_nike
516 endif
517 endif
518 c
519 c ----- stent materials -----
520 c
521 if (%inike.eq.1) then
522     if (%isim_mode.eq.1.or.%isim_mode.eq.2) then
523         include istent.mats_nike_solid
524         echo NiTi model for radial force/flat plate analysis
525     elseif (%isim_mode.eq.3) then
526         include istent.mats_compress_nike_solid
527         echo NiTi model for predelivery compression strain
528     elseif (%isim_mode.eq.4) then
529         include istent.mats_compress_nike_solid
530         echo NiTi model for initial expansion strain
531     elseif (%isim_mode.eq.5) then
532         include istent.mats_nike_freq_solid
533         echo NiTi model for frequency analysis
534     elseif (%isim_mode.eq.6) then
535         include istent.mats_nike_solid
536         echo NiTi model for anatomy deployment
537     endif
538 c
539 elseif (%inike.eq.0) then

```

FIG. 8L

```

540  if (%isim_mode.eq.1.or.%isim_mode.eq.2) then
541      include istent.mats_dyna_solid
542      echo NiTi model for radial force/flat plate analysis
543  elseif (%isim_mode.eq.3) then
544      include istent.mats_compress_dyna_solid
545      echo NiTi model for predelivery compression strain
546  elseif (%isim_mode.eq.4) then
547      include istent.mats_compress_dyna_solid
548      echo NiTi model for initial expansion strain
549  elseif (%isim_mode.eq.6) then
550      include istent.mats_compress_dyna_solid
551      echo NiTi model for anatomy deployment
552  endif
553 endif
554 c
555 c .... cylindrical compression for radial force or predelivery compression
556 c
557 if (%isim_mode.eq.1.or.%isim_mode.eq.3.or.%isim_mode.eq.4.or.%isim_mode.eq.6) then
558 c
559  if (%isym.eq.1) then
560      include cylinder.parts_sym
561  else
562      include cylinder.parts
563  endif
564 endif
565 c
566 if (%inike.eq.1) then
567      include cylinder.materials_nike
568 elseif (%inike.eq.0) then
569      include cylinder.materials_dyna
570 endif
571 c
572 stp .0001
573 c
574 c .... Constrain stent node(s) in z-direction for time-hist analysis
575 c
576 if (%isim_mode.ne.5) then
577 merge
578 c
579 c .... nset for 3-segment model
580 c nset zconstr = 1 8149 8687 9215 9747 ;
581 c echo ** Bottom 12-crown node list Constrained in Z-translation **
582 c
583 c .... nset for 6-crown only
584 echo ** Bottom 6-crown node list constrained in z-dir **
585 nset zconstr = 1 43 97 151 448 ;
586 b nset zconstr dz 1 ;
587 endif
588 c

```

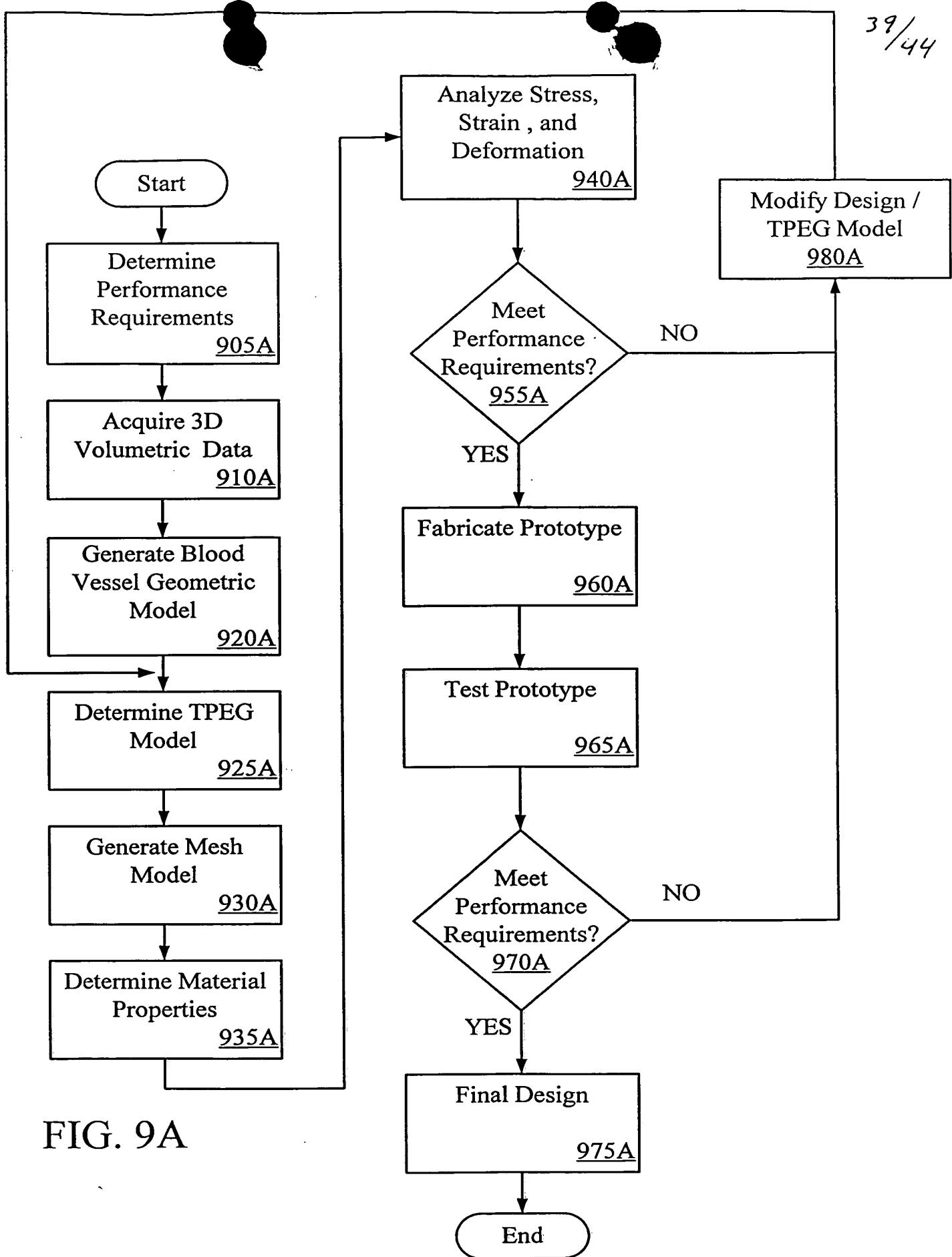


FIG. 9A

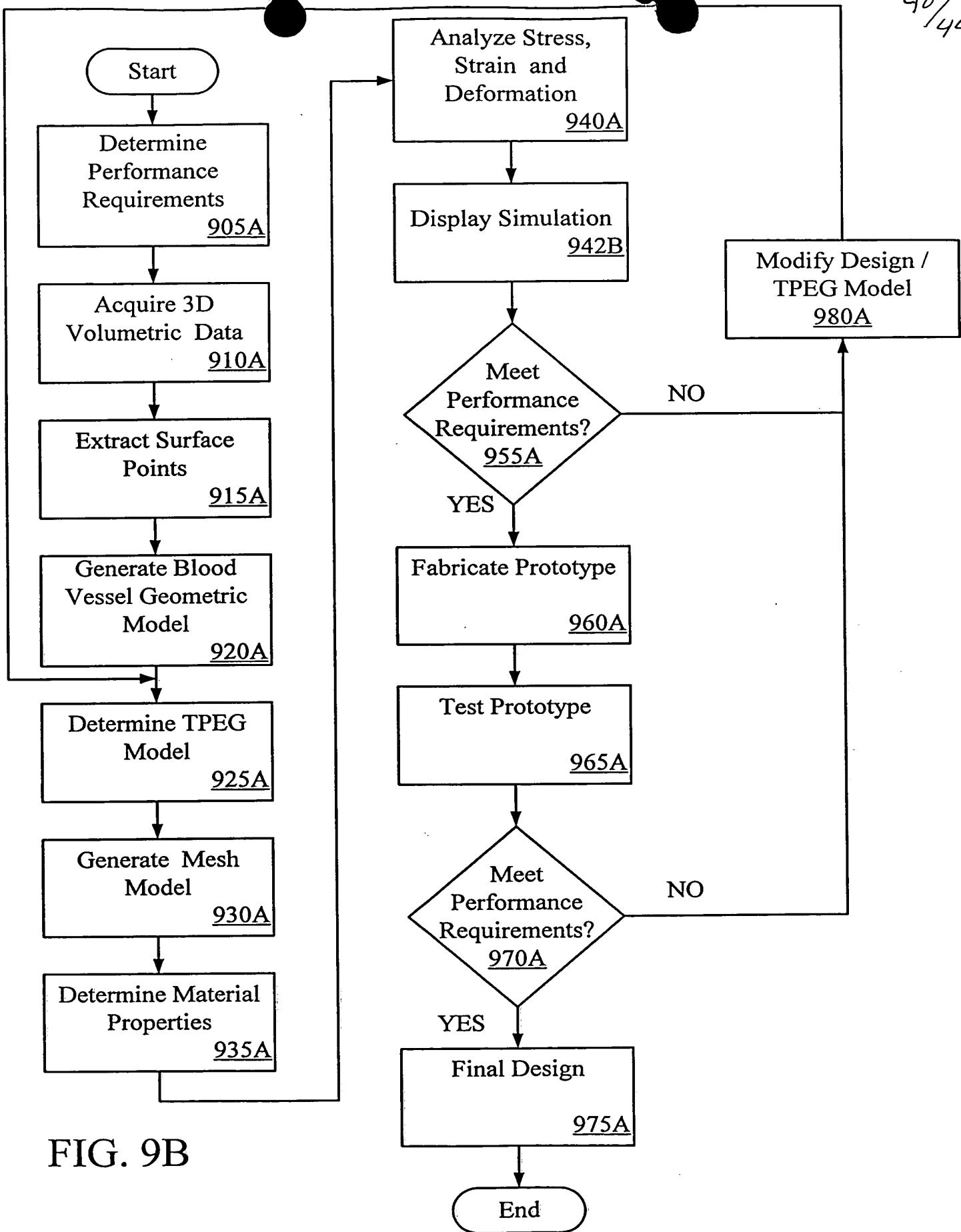


FIG. 9B

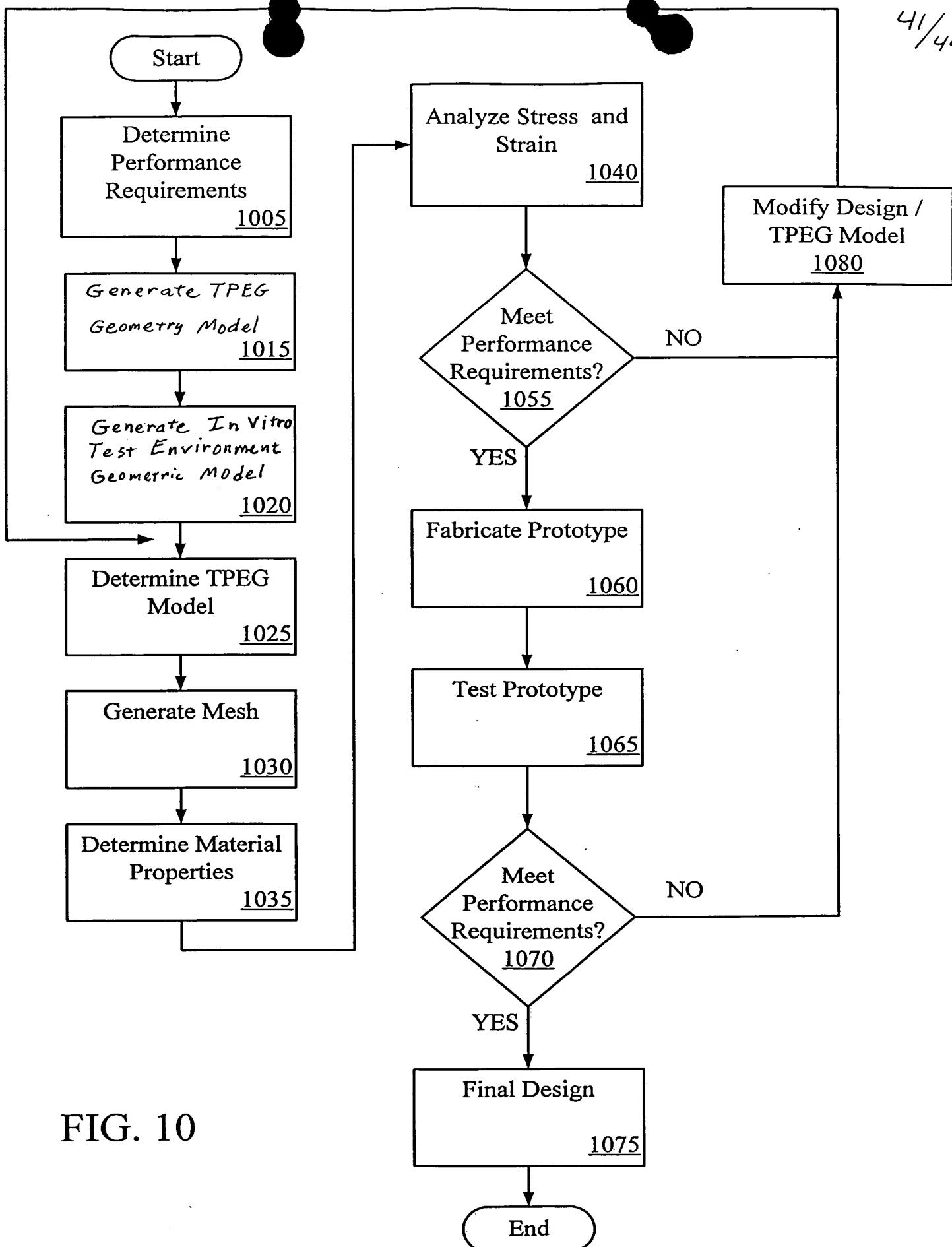


FIG. 10

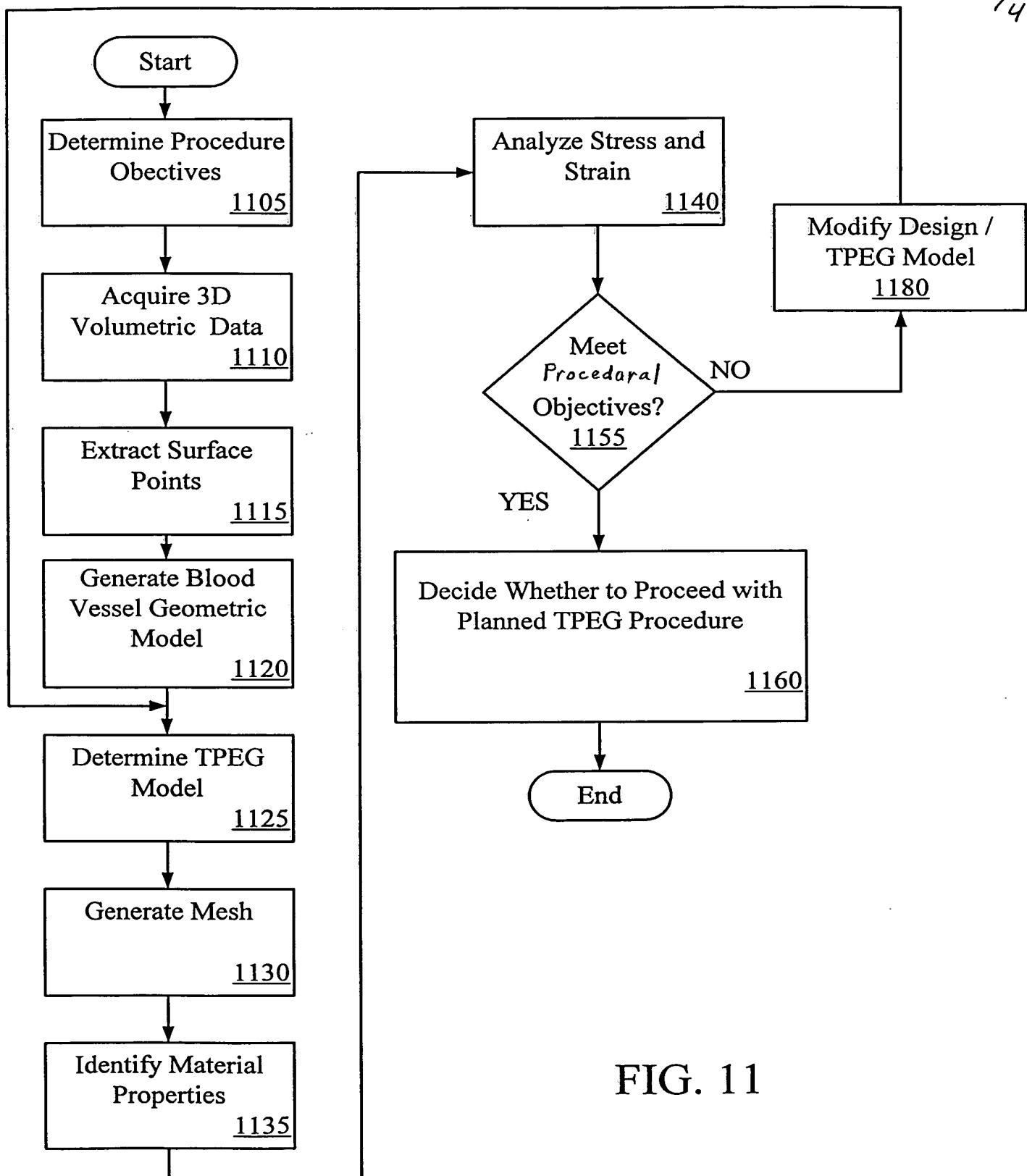
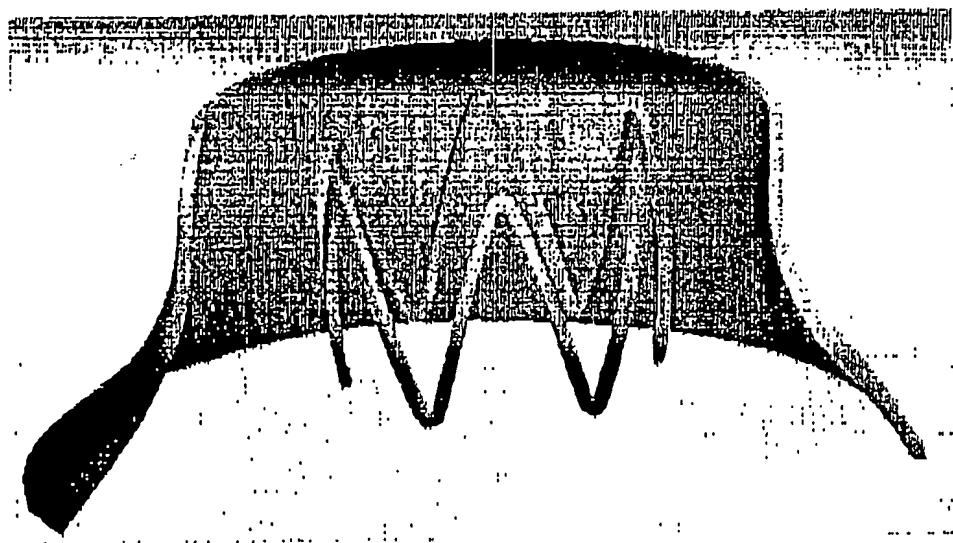


FIG. 11

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FIG. 12



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FIG. 13

